Qualitative Laser-Induced Incandescence Measurements of Soot Emissions During Transient Operation of a Port Fuel-Injected Engine

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Proceedings of
The Fifth International Symposium on Diagnostics and Modeling of Combustion in Internal Combustion Engines
COMODIA 2001
July 1-4, 2001, Nagoya, Japan

ABSTRACT

Beginning in 2004, all passenger cars and light-duty trucks sold in the U.S. will be required to meet the same emission regulations regardless of the fuel type (EPA Tier 2). Thus, for the first time gasoline-fueled vehicles will have to meet particulate matter emission standards that in the past have only been required of diesel-fueled vehicles. It is expected that contemporary port fuel-injected (PFI) engines with catalysts will be able to meet the requirements, which are currently based on particulate mass. In contrast, it is uncertain at this time whether the new generation of direct-injection gasoline engines can achieve certification. Furthermore, health risks are more strongly correlated with particle size and number density than with mass concentration. If new regulations are based on these parameters, gasoline engines will come under closer scrutiny.

To help meet these new and anticipated regulations, improved particulate measurement techniques are needed. The two capabilities most urgently required are fast response to follow transients, and high-sensitivity to measure small amounts in short times. Laser-induced incandescence (LII) offers these capabilities.

The purpose of this paper is to demonstrate the use of LII for making time-resolved measurements of soot volume fraction during engine transients. The measurements presented were made at the exhaust-port exit of a production, four-valve, PFI spark-ignition engine with only one active cylinder. Optical access to the exhaust flow between the head and exhaust manifold was achieved by an optical flow channel with three windows. which permitted a laser beam to cross the exhaust steam while observed from above. Planar LII imaging was used to investigate the spatial distribution of soot across the exhaust port; analog LII measurements were made to measure the soot volume fraction during transient engine operation.

The planar LII images obtained in the exhaust port show that soot concentration varies widely both spatially and temporally, from cycle-to-cycle. For some cycles the soot distribution was relatively uniform, whereas for others it varied greatly between the two valves. On average, the amount of soot emitted from each valve was different.

For open-valve injection, the soot volume fraction increased rapidly over the first 20 cycles of a simulated cold start, and then continued to increase at a slower rate for the duration of the 300 cycle test. In contrast, for closed-valve injection the soot volume fraction rose very quickly to a maximum in less than 10 cycles, and then fell rapidly to a low concentration by about 50 cycles, after which it continued to fall gradually for the remainder of the test. We believe the large differences in the soot behavior for these two cases is related to the dynamics of the in-cylinder wall films, and in particular, to the changing composition of the films as wall temperatures increase.

For a snap-throttle transient, where the manifold pressure was suddenly increased from 40 to 98 kPa, the soot volume fraction increased steadily during the throttled period, fell to near zero at the time of the snap-throttle, and then increased steadily to a value approximately ten times greater than for the throttled period. Severe window fouling occurred during the wide-open-throttle portion of this test, resulting in a 30% loss in laser beam transmission after engine shutdown. This fouling problem limited this study to qualitative observations, and represents the main disadvantage of optical techniques for engine exhaust studies. Fortunately, it is a design problem that can be corrected, although at the expense of added complexity.